Characterization of Pressure Transducers for the KamLAND 4π Full-Volume Calibration System

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- Preliminary -

Abstract

The pressure transducers that were chosen for use with the KamLAND 4pi calibration system have been tested and characterized in water over a depth range of 6.5 m. The sensors were found to be accurate to 1.3 cm at a depth of 10 m of water. All sensors for the 4pi system will be tested for functionality and characterized in water before they are shipped to Japan. The final test and calibration of the pressure sensors will occur *in-situ* with a z-axis deployment of the pressure sensors in the detector using the new 4pi deployment hardware.

I. Test Setup

To test and characterize the performance of the pressure sensors a simple test setup was assembled. A 3/4' pipe-thread was screwed to the transducer, and this thread was screwed to a 15 meter hose. The hose was filled to the lip with water and the transducer end of the hose was placed at the base of a 6.5 meter stair well outside Building 88 at LBNL. (Initially, the pressure transducer data runs were done on the 3 meter stair case in the high bay in Building 88 but there was too much uncertainty introduced in the extrapolation of the trend from 3 meters to 10 meters.)

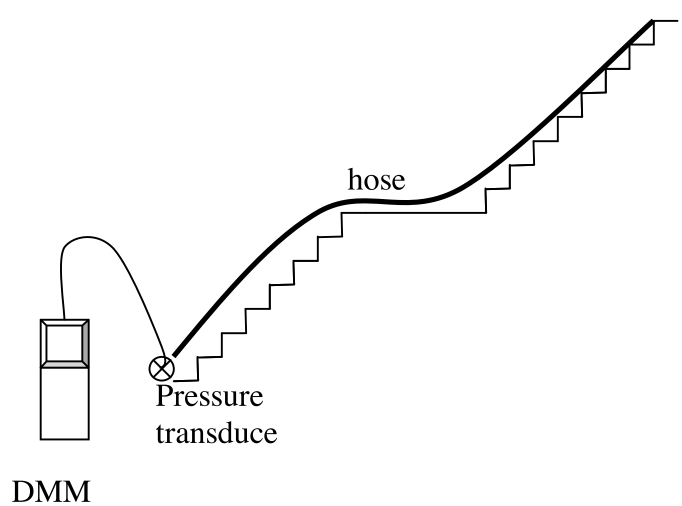


Figure 1: Schematic diagram of test setup for the characterization of the pressure sensor.

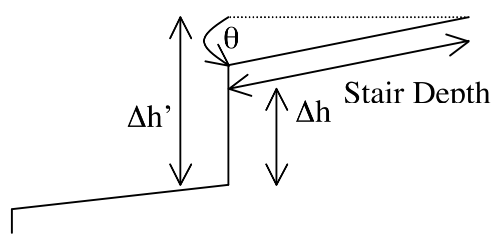
II. Description of test procedure

Having explored several options[1], we found that the best available pressure transducer test procedure was a "staircase" test. The top of the hose was moved down a step at a time, the meniscus exactly flush with the step's edge, and voltage readings were taken from the pressure transducer with a millivolt accurate DMM[2]. The height of each stair was then measured with a millimeter accurate measuring stick. This was done repeatedly (for statistics), with care each time to maintain the miniscus at the edge of the pipe thread of the hose, replenishing water if need be.

III. Height Measurements

It was noted that the collected data had slope discontinuities every other 2m, roughly corresponding to the 1 meter platforms every 10 steps down the stairwell. It occurred to me that these platforms might not be entirely level, and were therefore making an unmeasured contribution to the depth of fluid exerting pressure on the transducer.

Figure 2: Height measurement of the steps



I procured a graduated cylinder from 137 and a high precision protractor from the machine shop, and measured the angle of declination of each step and platform with respect

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[1] Alternative pressure transducer tests setups:

The pressure transducer could be packaged in a water-proof enclosure and submerged in a pool of water. However, there are no pools of sufficient depth at hand, and one would incur substantial uncertainty from the extrapolation alone, masking the underlying pressure transducer error.

One could expose the pressure transducer to gas flow regulated to a known pressure. But there are no regulators of sufficient accuracy on hand at lbl.

One could hang a hose so that it dangles vertically from a sufficiently large height with the pressure transducer affixed water tight at the base of the hose and fill the hose gradually with increments of water from a volumetric flask. Building 88's roof is about 10m high, so this seemed an ideal setting for such a test. However, as the hose is a 20m hose, some length of the hose would inevitably be non-vertical, and after a few such test runs from the top of building 88, it was apparent that this method tends to trap air bubbles in the hose, and that the pressure the transducer observed would jump as these bubbles percolated from the vertical to the slanted segment of the hose.

[2] Initially, a 10 millivolt accurate DMM was used, but it turned out the transducer's response was roughly 2mV/cm, so that cm accuracy is only possible with a millivolt accurate DMM

to the true horizontal as represented by the meniscus of water in the graduated cylinder. The depth of the steps and platforms were also measured.

The steps tend to be about 30 cm deep, so a single degree of declination introduces an error of about 1/12 cm . The platforms were about 1.85 meters deep, so a single degree of declination amounts to about a half a centimeter. Most of the steps had an angle of declination on the order of seconds of arc, and so had no effect on the least significant figure. But the platform and a few other steps had angles of declination on the order of a degree, modifying the height on the order of a centimeter.

These may seem like negligible differences. As it turns out, however, the error in the height measurements made a substantial contribution to extrapolation error, the difference between an uncertainty of 2 cm and 1 cm at a depth of 10 m.

Table 1 gives height measurement data. "Δh" is the vertical distance between steps measured at the edge of the step, "θ" is the angle of declination, and "stair depth' is stair depth. "Δh'" height difference between steps with the declination taken into account. "h" is the cumulative height of the n^{th} step.

Table 1: Height Measurement Data

Δh' (cm)	Δh (cm)	θ	stair depth (cm)	h (cm)
17.8	17.8	60'	27.1	639.9
19.2	19.2	60'	29.1	622.1
18.6	18.6	60'	29.5	602.9
19	19	60'	28.8	584.3
18.1	18.1	180'	29.7	565.3
18.7	18.7	120'	28.8	547.2
17.9	17.9	120'	29	528.5
18.9	18.9	120'	28.9	510.6
19.1	19.1	120'	28.7	491.7
18.6	18.6	180'	29.9	472.6
18.1	18.1	60'	29.2	454
18.5	18.5	120'	29.1	435.9
18.9	18.9	120'	28.8	417.4
18.7	17.7	2	185	398.5
19	18.7	3	27.4	379.8
19.1	19.1	180'	28.5	360.8
19	19	60'	29.2	341.7
18.5	18.5	120'	28.8	322.7
19.5	19.5	120'	29.4	304.2
18.5	18.4	1	28.5	284.7
19.5	19.5	120'	29.2	266.2
18.5	18.5	180'	28.4	246.7
19	19	120'	27.3	228.2
19.5	19.5	120'	27.5	209.2
19	18.9	1	28.5	189.7
19	19	120'	28.5	170.7
19	19	180'	29.2	151.7
19	18.9	240'	28.9	132.7
18.5	16.5	4	181	113.7
19	18.9	300'	29.4	95.2
18.7	18.7	120'	28.6	76.2
19.5	19.5	180'	28.9	57.5
18.5	18.5	180'	29.2	38
19.5	19.5	120'	28.9	19.5

Table 2: Height and Pressure Transducer Response

Different measurements (taken on the same day) are labeled DMM0, DMM1, DMM2, DMM3. We found that measurements take on different days could not be correlated as well because of atmospheric pressure variations. In KamLAND we can calibrate the depth measurement of the pressure sensors against the liquid level of the scintillator and hence eliminate the atmospheric pressure dependence of the depth measurement.

Step	**h (cm)**	**DMM0**	**DMM1**	**DMM2**	**DMM3**
34	639.9	3.946	3.946	3.945	3.944
33	622.1	3.906	3.906	3.905	3.904
32	602.9	3.86	3.859	3.858	3.856
31	584.3	3.816	3.812	3.814	3.815
30	565.3	3.776	3.772	3.774	3.775
29	547.2	3.73	3.729	3.728	3.727
28	528.5	3.687	3.68	3.684	3.686
27	510.6	3.64	3.637	3.638	3.639
26	491.7	3.6	3.597	3.596	3.595
25	472.6	3.556	3.553	3.552	3.551
24	454	3.515	3.512	3.511	3.51
23	435.9	3.472	3.468	3.469	3.469
22	417.4	3.425	3.424	3.423	3.421
21	398.5	3.382	3.378	3.377	3.376
20	379.8	3.355	3.353	3.351	3.35
19	360.8	3.308	3.304	3.303	3.301
18	341.7	3.268	3.265	3.264	3.264
17	322.7	3.228	3.224	3.226	3.225
16	304.2	3.176	3.171	3.174	3.17
15	284.7	3.134	3.13	3.132	3.13
14	266.2	3.091	3.086	3.088	3.086
13	246.7	3.048	3.044	3.046	3.044
12	228.2	3.006	3.004	3.002	3.003
11	209.2	2.963	2.96	2.961	2.96
10	189.7	2.921	2.919	2.917	2.918
9	170.7	2.878	2.876	2.874	2.873
8	151.7	2.835	2.833	2.831	2.83
7	132.7	2.793	2.79	2.788	2.789
6	113.7	2.75	2.748	2.747	2.746
5	95.2	2.707	2.705	2.706	2.704
4	76.2	2.665	2.664	2.662	2.661
3	57.5	2.622	2.619	2.617	2.619
2	38	2.579	2.576	2.575	2.574
1	19.5	2.536	2.533	2.531	2.53

IV. Data Analysis Technique

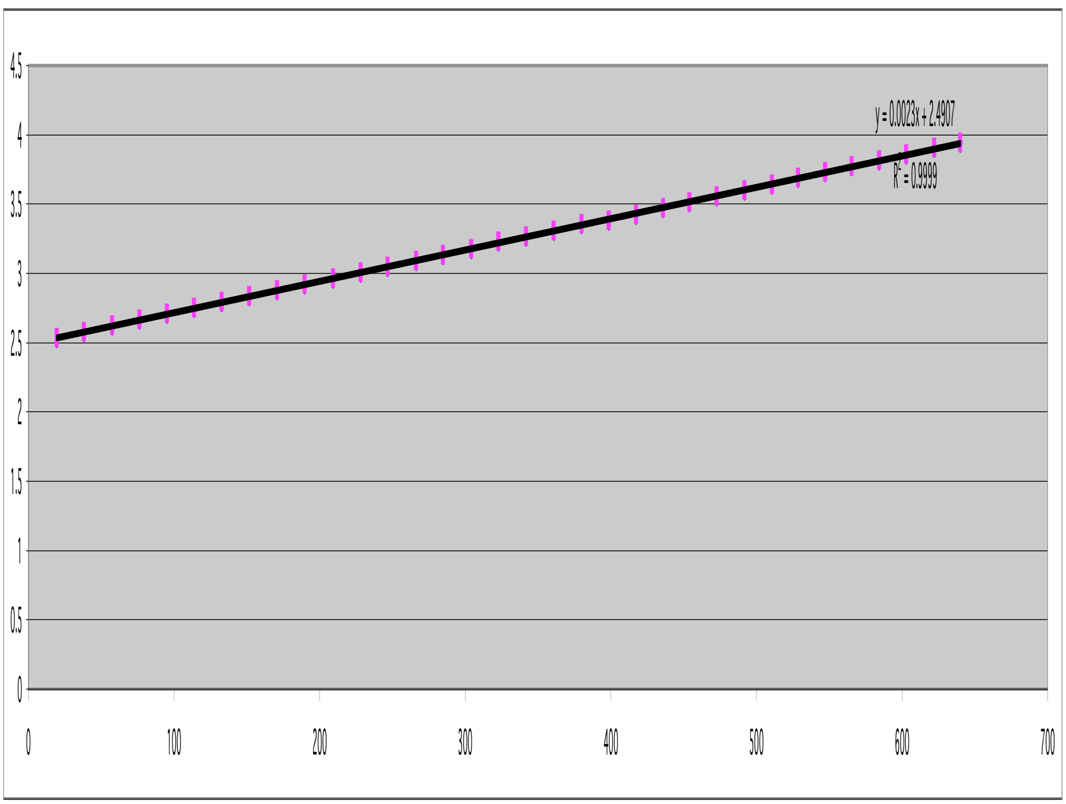
The least squares method was applied to the graph of average DMM reading vs. height, so that the slope and intercept were extracted as:

$$m = \frac{\sum_{i=1}^{N} x_i \sum_{i=1}^{N} y_i - N \sum_{i=1}^{N} x_i y_i}{\left(\sum_{i=1}^{N} x_i \right)^2 - N \sum_{i=1}^{N} x_i^2}$$

$$b = \frac{\sum_{i=1}^{N} y_i - m \sum_{i=1}^{N} x_i}{N}$$

We find m = 0.00227 V/cm, and b = 2.48771889. The plot of the linear best fit follows:

Figure 3



The regression correlation was calculated with the formula $\sigma_r = \sqrt{\dfrac{\sigma_y^2 - m^2 \sigma_{yy}^2}{N-2}}$, where $\sigma_y^2 = \sum_{i=1}^{N} \left(y_i - m x_i - b \right)^2$ and $\sigma_{yy}^2 = \sum_{i=1}^{N} \left(y_i - y \right)^2$. The actual values are in the following tables:

Sy	Syy	sr
6.2074E-05	0.50023377	0.00464864
6.7297E-05	0.445252	
2.2088E-05	0.38473743	
8.0482E-06	0.33208949	
3.4577E-05	0.28758772	
1.2873E-06	0.24061189	
5.6511E-07	0.19915875	
3.5408E-05	0.16041792	
2.1471E-05	0.12889684	
2.8771E-05	0.0992389	
1.7866E-05	0.07508809	
3.2746E-05	0.05360246	
0.00010124	0.03432574	
0.00014994	0.01967625	
1.6963E-05	0.0130581	
1.1841E-06	0.00435891	
1.1776E-05	0.00074377	
4.865E-05	0.00014952	
1.6929E-05	0.00425468	
1.4125E-06	0.01133755	
9.1683E-06	0.02256843	
1.2142E-06	0.03704776	
8.8615E-07	0.05486273	
4.2E-07	0.07671678	
1.6331E-06	0.10190648	
6.7438E-07	0.13157156	
7.4734E-07	0.16461516	
2.7482E-06	0.20068424	
6.0077E-06	0.24032343	
4.4589E-06	0.28353276	
7.0485E-06	0.33059963	
1.6092E-06	0.38282427	
4.816E-06	0.43821479	
3.6616E-07	0.49769913	
#N/A	5.95798692	
0.00072209		

We are now able to compute the uncertainty in our extrapolation to 10 meters, with the formula for the extrapolation error at *X:*

$$\sigma_i(X) = \sigma_r \sqrt{\frac{1}{N} + \frac{\left(X - \bar{x}\right)^2}{\sum_{i=1}^{N} x_i^2 - \frac{1}{N}\left(\sum_{i=1}^{N} x_i\right)^2}}.$$

The uncertainty thus calculated is then 0.0029939 V, which corresponds to about 1.3 cm.

V. Results

The pressure transducer's response is linear with the following parameters describing a linear fit: m = 0.00227 V/cm, and b = 2.48772. The extrapolation uncertainty at 10 meters is 0.00299 V, roughly 1.3 cm, where cm here means cm of water.

References

[1] For specifications of the pressure sensors see:
http://kmheeger.lbl.gov/kamland/4pi/design&engineering/data_sheets/

Questions & Comments?

For questions and comments please contact:

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